



Jet Propulsion Laboratory
California Institute of Technology

Modeling Earthquake-Induced Travelling Ionospheric Disturbances

Xing Meng¹, Attila Komjathy¹, Olga P Verkhoglyadova¹, Giorgio Savastano²,
and Anthony J Mannucci¹

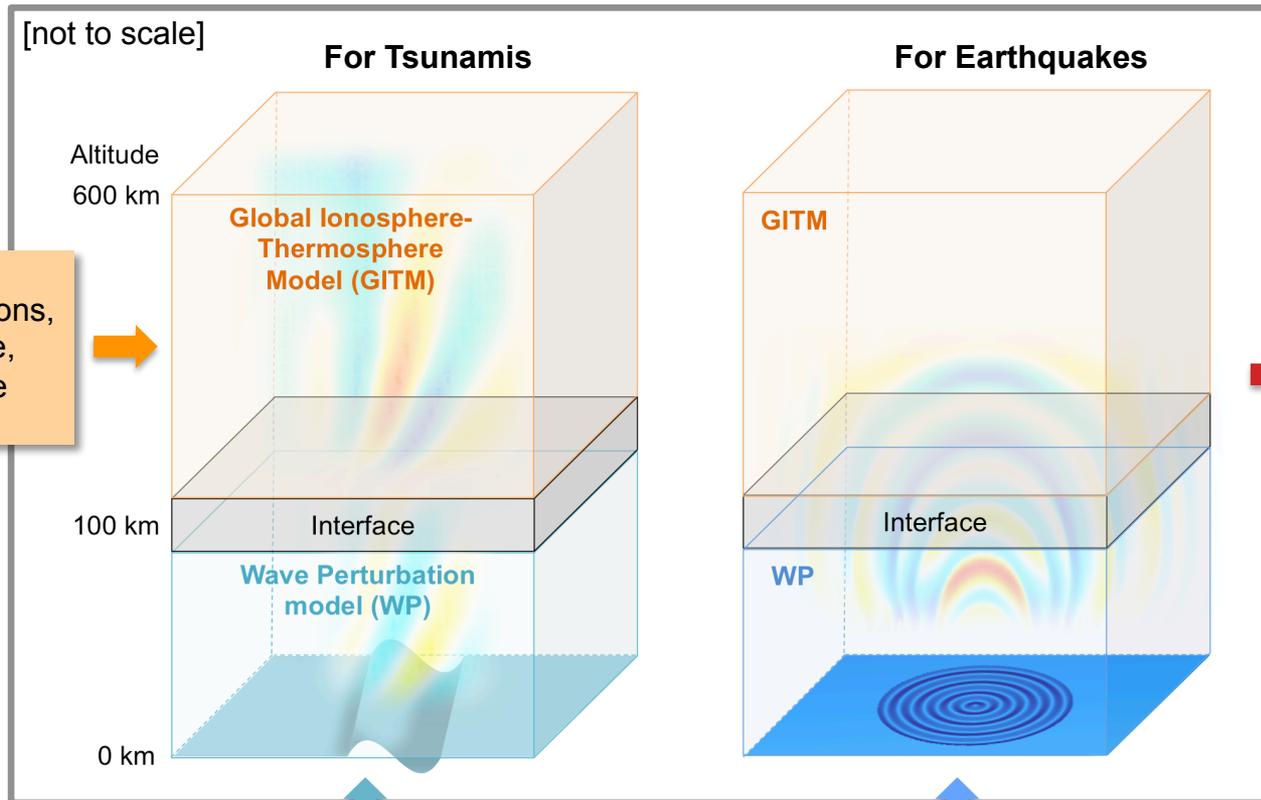
¹*Jet Propulsion Laboratory, California Institute of Technology, USA*

²*University of Rome “La Sapienza”, Italy*

Outline

- Introduction of Wave Perturbation – Global Ionosphere Thermosphere Model (WP-GITM)
- Event Simulations
 - 2011 Tohoku-Oki earthquake
 - 2015 Illapel earthquake
- Summary

WP-GITM Infrastructure



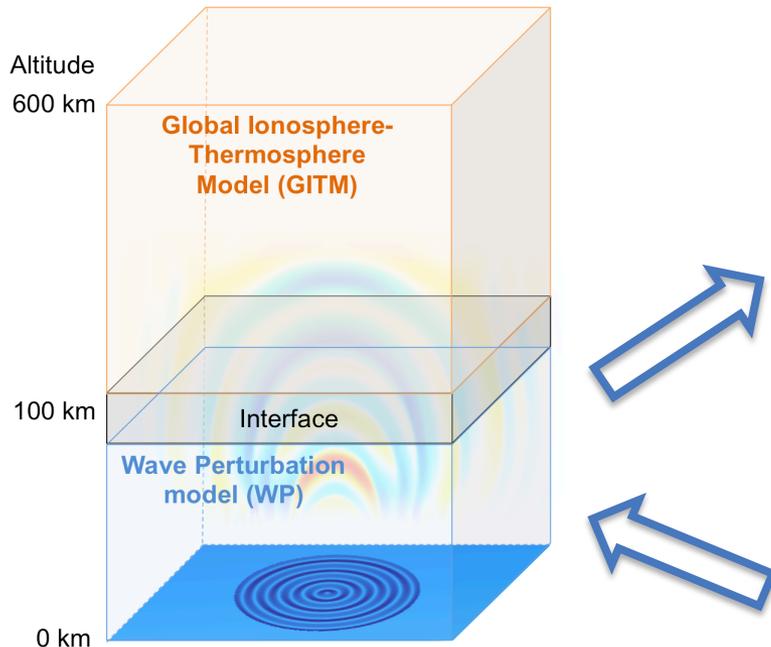
Input I
solar wind conditions,
solar irradiance,
auroral particle
precipitation

Input II
Tsunami wave
characteristics

Input II
vertical velocity data

Output
Ionospheric and
thermospheric
disturbances

WP-GITM for Earthquake-Ionosphere Coupling



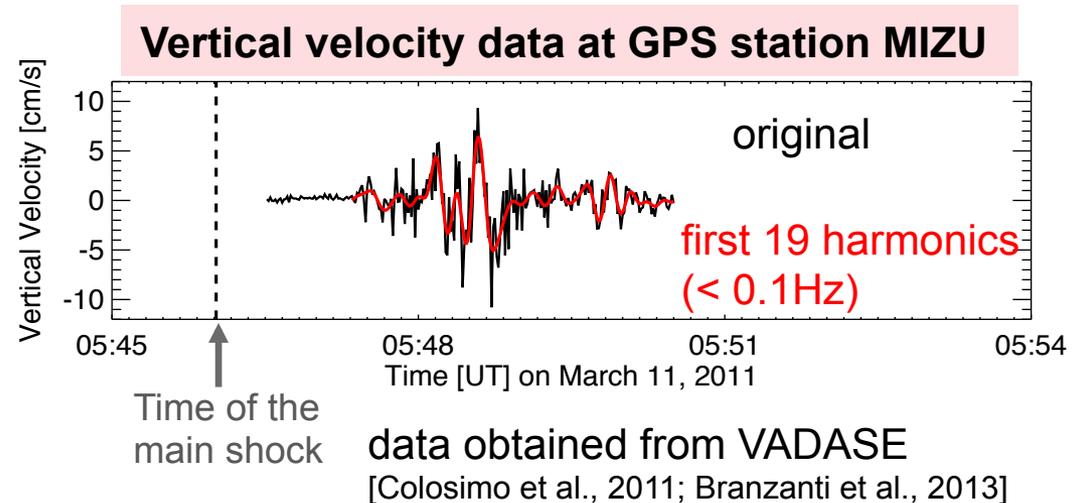
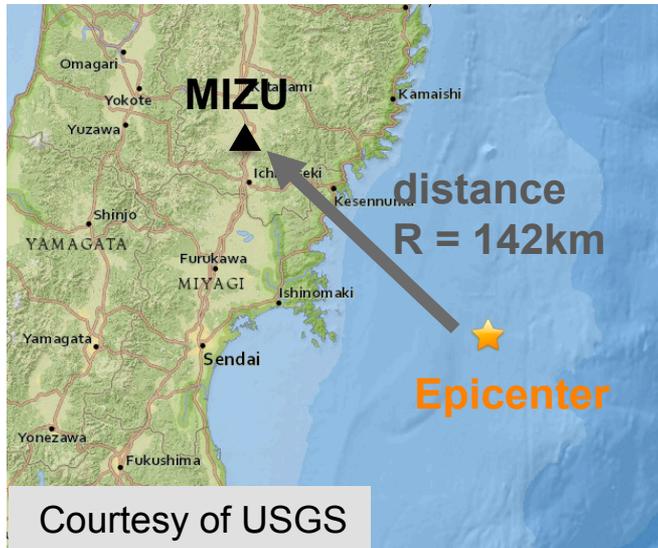
Major Assumptions

1. Epicenter as a point source of spherical waves in the neutral atmosphere
2. Seismic-atmosphere coupling through surface vertical velocity

Key New Modeling Developments in WP

1. Spherical acoustic-gravity waves from a point source
2. Source (velocity time series) specification with seismic measurement

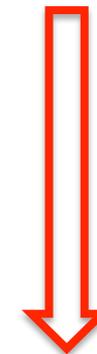
2011 Tohoku-Oki Event: Source Specification



Seismic wave amplitudes decay due to geometrical spreading, intrinsic absorption, and scattering attenuation.

Uncertainty in Q^{-1} : For S-waves between 0.01Hz and 0.1Hz, $Q^{-1} = 0.05 \sim 0.0005$; For S-waves < 0.01Hz, unknown. [Sato et al., 2012]

We set $fQ^{-1} = 0.005$



Amplitude increase towards epicenter: multiply by

$$e^{-\pi R f Q^{-1} / v} / R$$

[Sato et al., 2012]

Vertical velocity at Epicenter

2011 Tohoku-Oki Event Simulation

Simulated local region:

31°N – 47°N, 135°E – 151°E

Simulated time interval:

05:40 UT – 07:00 UT

11 March 2011

Local time ~ 3PM

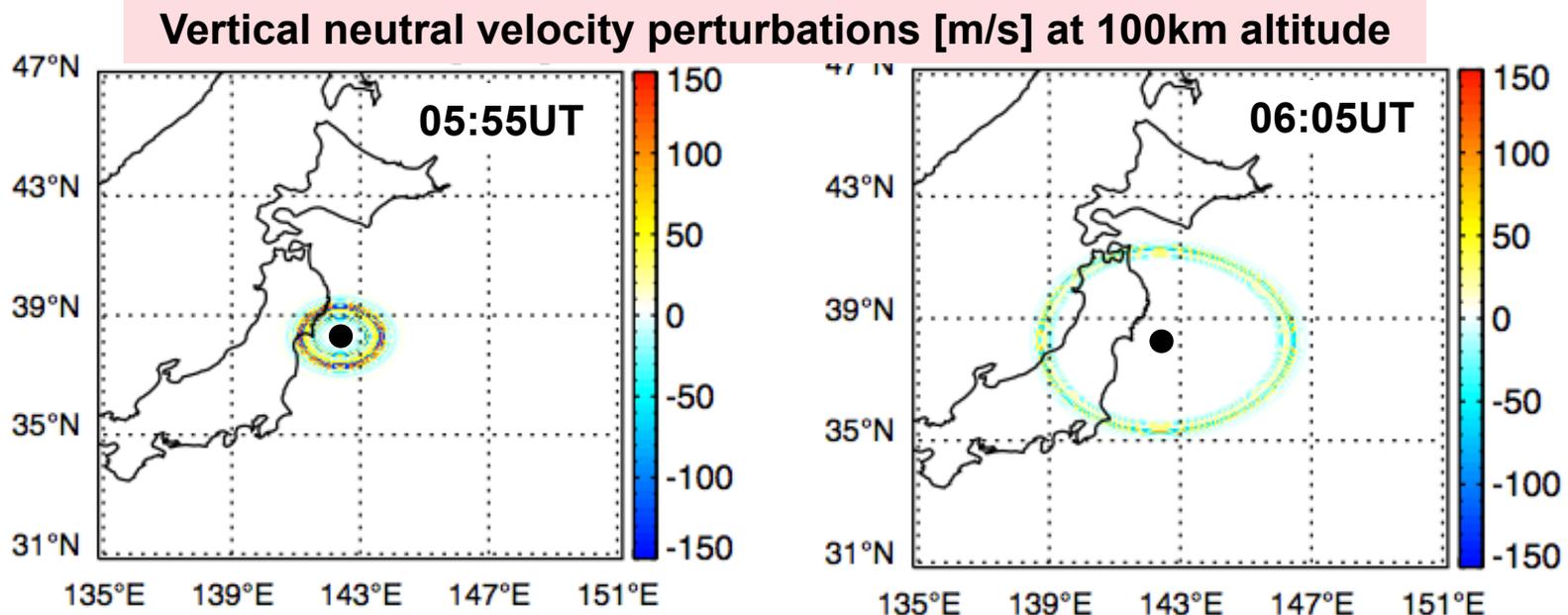
Spatial resolution:

0.02° horizontally

1/5 local scale height vertically (1 km – 10 km)

Temporal resolution: ~ 1 second

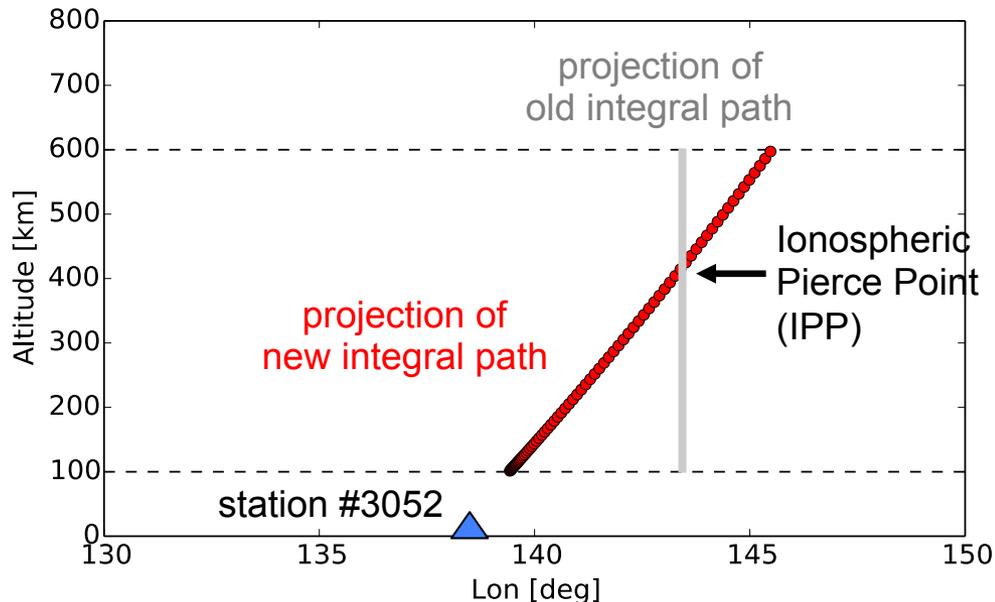
Input: vertical velocity at epicenter



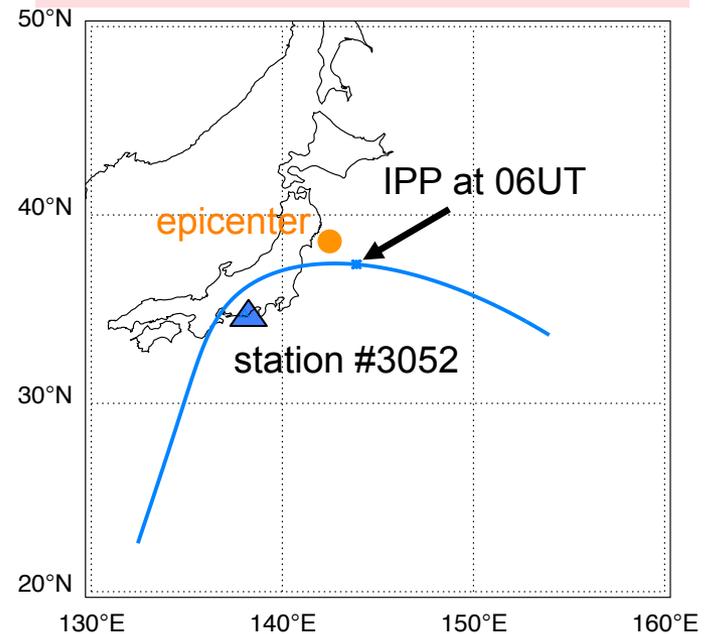
Tohoku Event Simulation: Comparison with GPS data I

- **New model feature:** Tracking receiver-to-satellite total electron content (TEC) perturbations time-dependently, which can be directly compared to slant TEC perturbations retrieved from the GPS data.

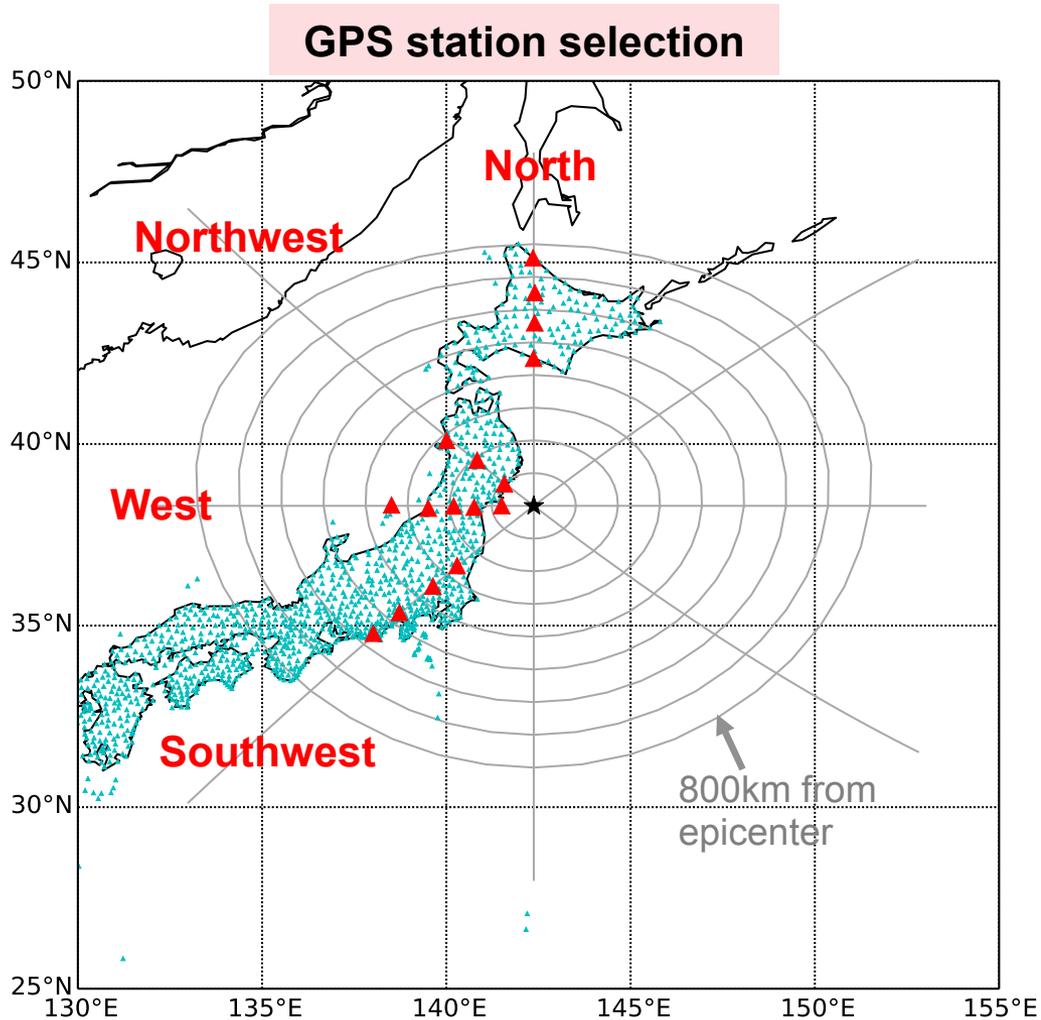
**Electron density integral path
at 06UT on 11 March 2011
station #3052 GPS26**



**IPP trajectory for
station #3052 and GPS26**



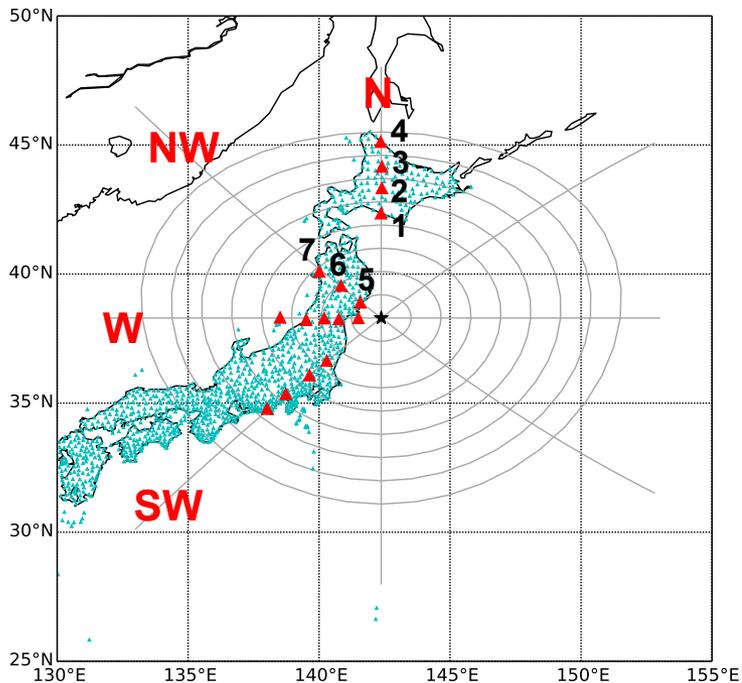
Tohoku Event Simulation: Comparison with GPS data II



Station selection criteria

- distance from the epicenter
- direction: N, NW, W, SW

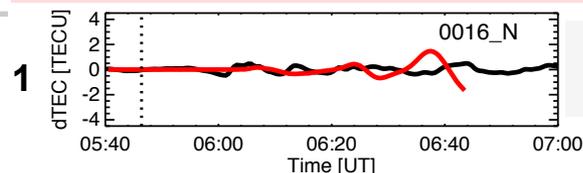
Tohoku Event Simulation: Comparison with GPS data III



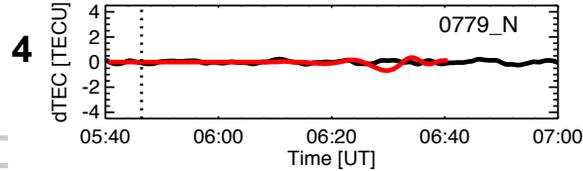
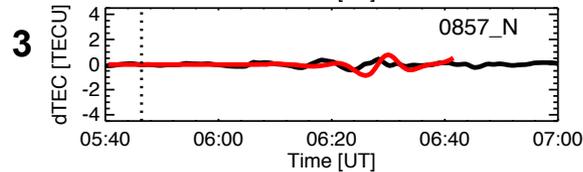
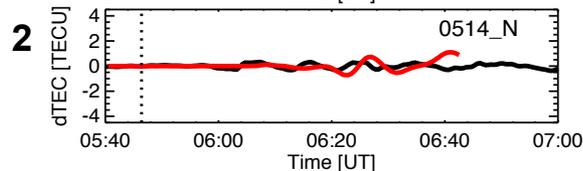
North stations

Northwest stations

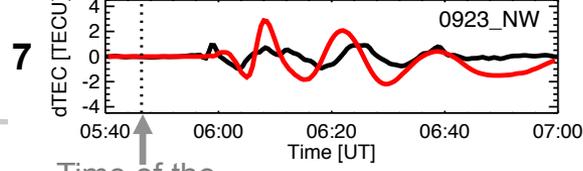
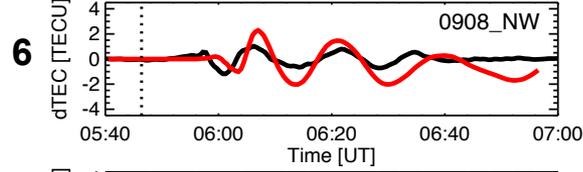
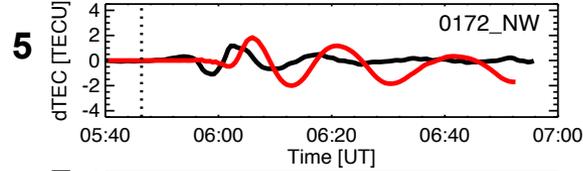
TEC perturbations GPS26



simulation
GPS-derived



Increasing distance from epicenter



Increasing distance from epicenter

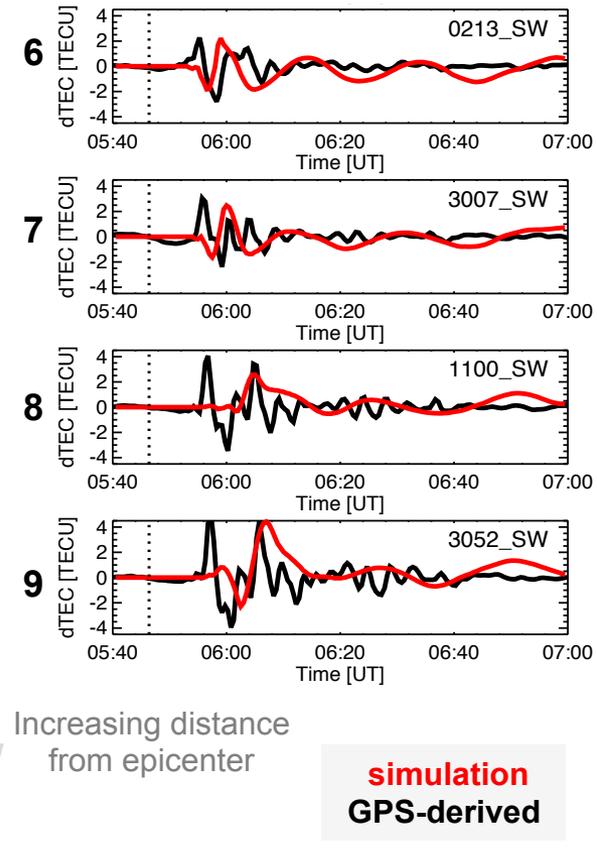
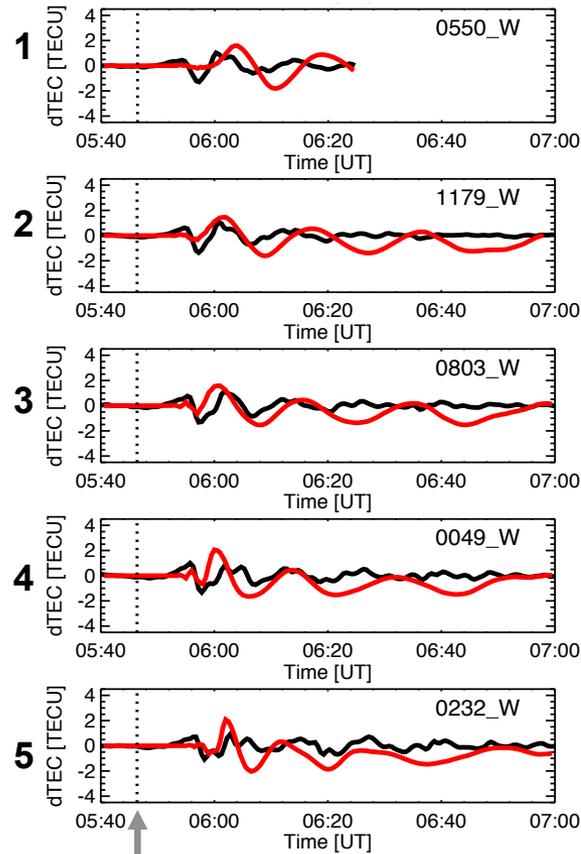
Time of the main shock

Tohoku Event Simulation: Comparison with GPS data IV

TEC perturbations GPS26

West stations

Southwest stations

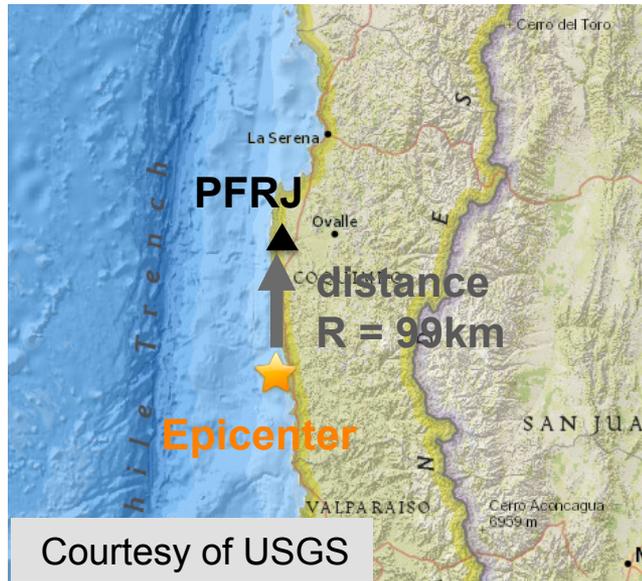


Increasing distance
from epicenter

simulation
GPS-derived

Time of the
main shock

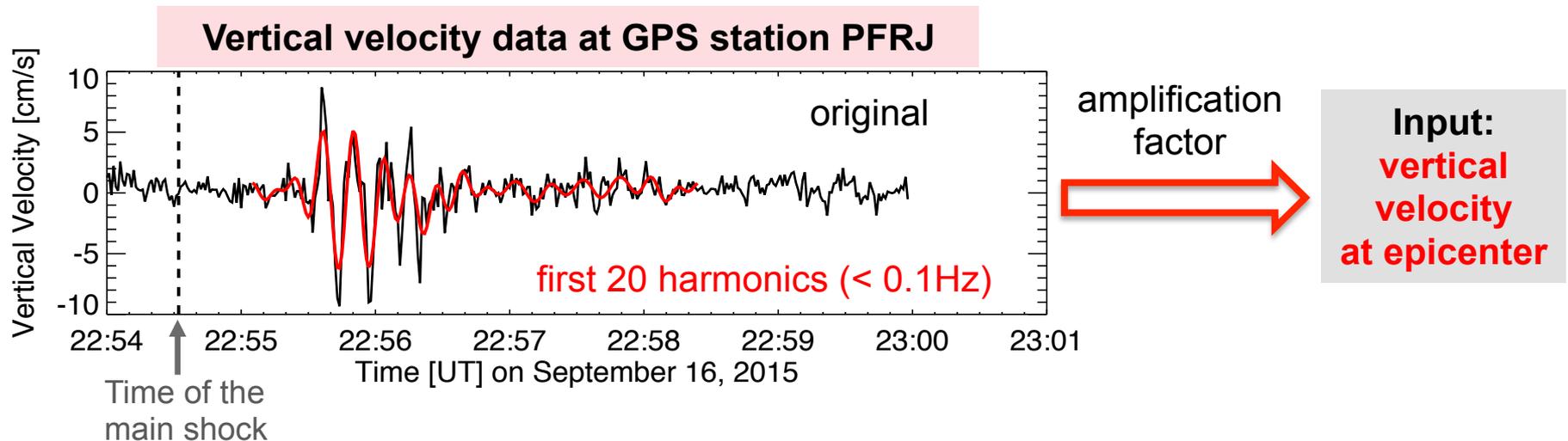
2015 Illapel Event Simulation



Simulated local region:
20°S – 40°S, 80°W – 60°W

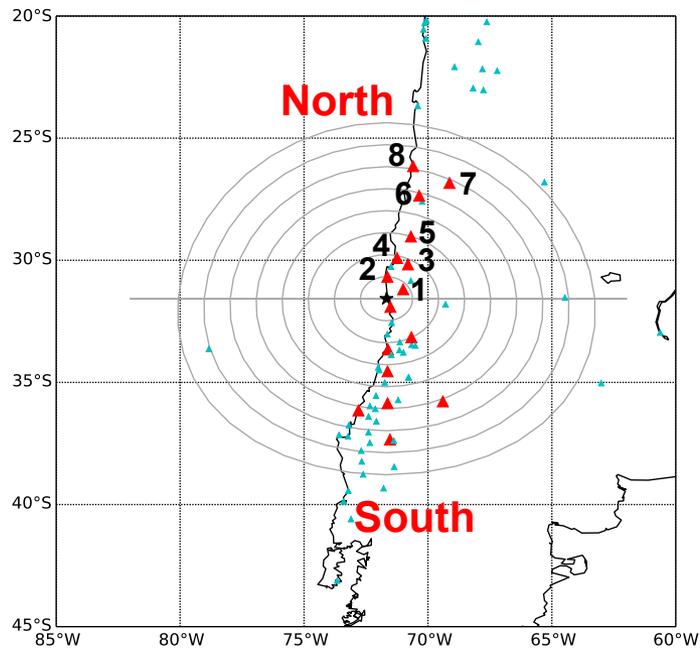
Simulated time interval:
22:50 UT – 23:59 UT on 16 September 2015
Local time ~ 7PM

Spatial resolution:
0.02° horizontally
0.2 local scale height vertically



Illapel Event Simulation: Comparison with GPS data I

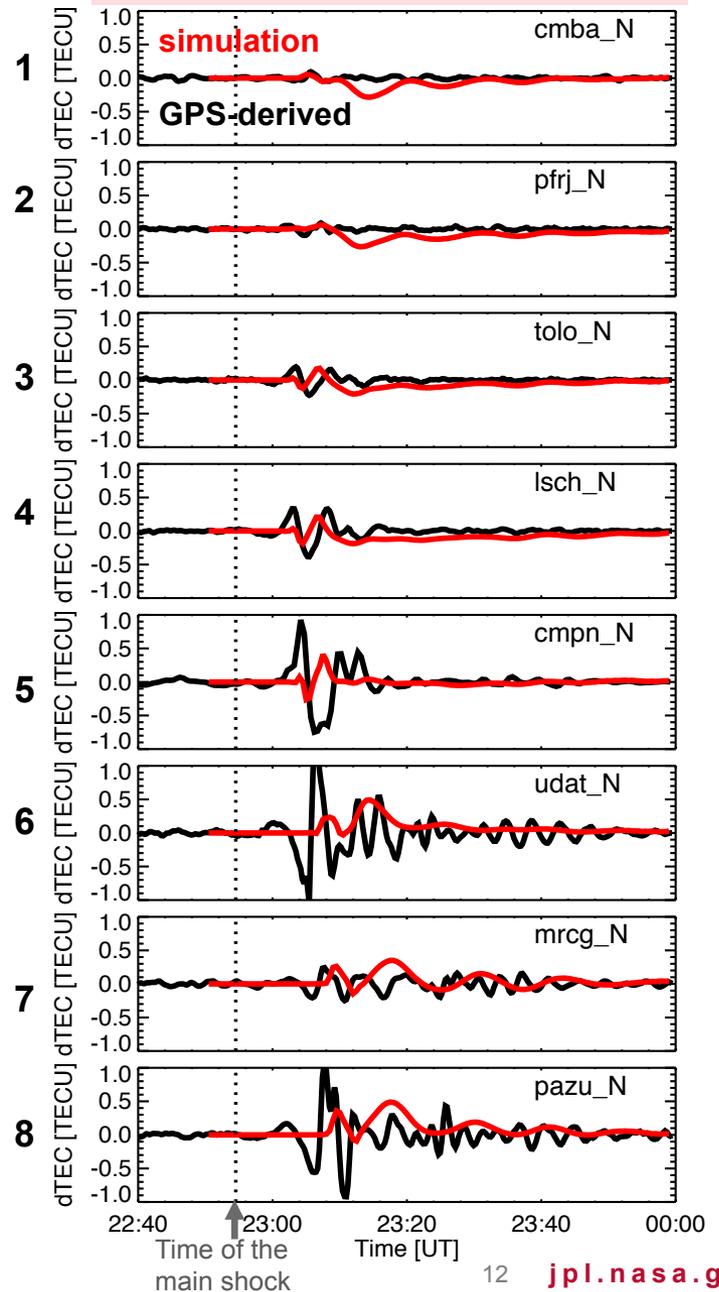
GPS station selection



North
stations

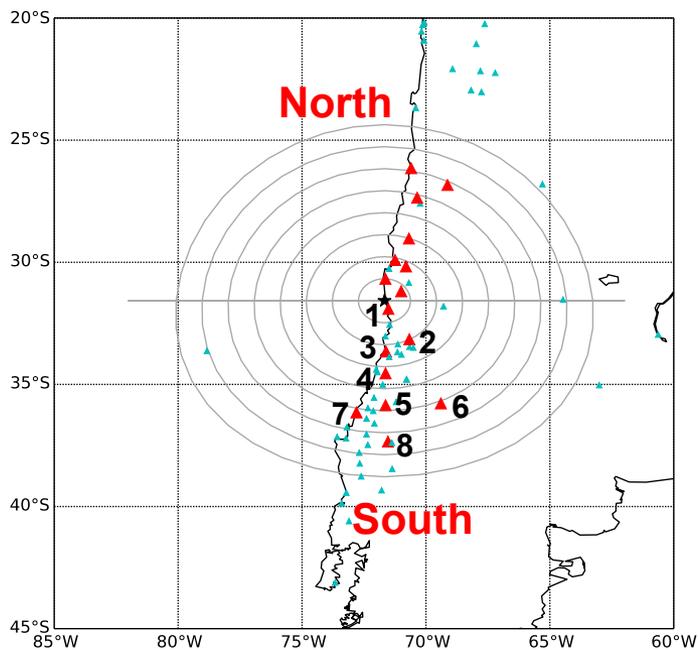
Increasing distance
from epicenter

TEC perturbations GPS58



Illapel Event Simulation: Comparison with GPS data II

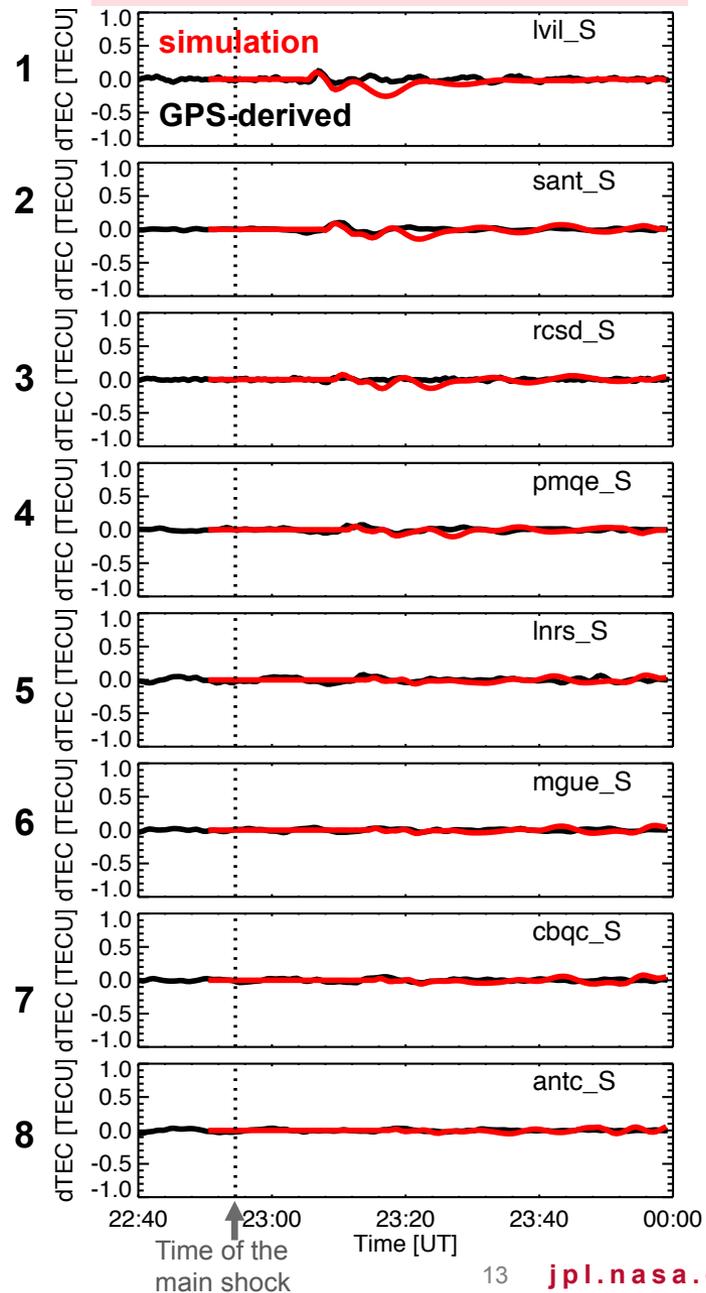
GPS station selection



South
stations

Increasing distance
from epicenter

TEC perturbations GPS58



Summary

- We have extended Wave Perturbation – Global Ionosphere Thermosphere Model (WP-GITM) capabilities to capture earthquake-induced ionospheric perturbations. WP-GITM can now be driven by seismic measurements.
- Modeling of the two large earthquake events show promising results: slant TEC perturbation magnitudes and arrival times are in agreement with GPS-derived TEC observations.
- Future work:
 - Extend modeling approach from the point source to an area source.
 - And consequently, model Rayleigh-surface-wave-induced ionospheric disturbances.

Acknowledgements

- The VADASE group: Dr. Mattia Crespi, Dr. Augusto Mazzoni, Michela Ravanelli and others, for providing high quality GPS ground velocity data.
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